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# High Temperature Void Formation Induced by $H_2O$ in Al Interconnection with SiN/PSG Passivation

**T.Ueda, S.Ueda, K.Yano and N.Nomura**

Semiconductor Research Center, Matsushita Electric Industrial Co.,Ltd.
3-1-1 Yagumo-nakamachi, Moriguchi, Osaka 570, Japan
TEL:+81-6-906-4897. Fax:+81-6-906-3451

A possible mechanism has been proposed for the round-shaped void formation in Al interconnection covered with SiN/PSG passivation at high temperature annealing above 400°C. $H_2O$ in PSG is confined by SiN as an $H_2O$ proof material and becomes high pressure steam. As a result, the high pressure $H_2O$ enhances the round shaped-voids in Al interconnection, accompanied by micro pores in PSG.

## 1. Introduction

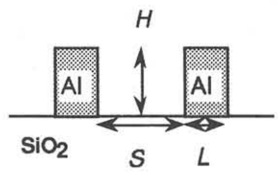
One of the most important issues in VLSI metallization reliability is an open failure caused by the so-called stress-induced void formation of Al interconnection. It has been reported that slit-like or wedge-like voids in low temperature mode are due to thermal expansion coefficient mismatches between surrounding materials [1]. However, the mechanism of round-shaped void formation of Al interconnection has not been well clarified, occurring during heating period at high temperature above 400°C when SiN/PSG passivation is used [2]. When SOG is used as an inter-level dielectric, the outgasing of $H_2O$ from SOG films was considered to affect the round-shaped void formation [3].

The purpose of this paper is to make clear the relation between $H_2O$ content in PSG and round-shaped void formation of Al interconnection covered with SiN/PSG passivation. The $H_2O$ behavior is studied by TEM, thermal desorption spectroscopy (TDS) and stress measurement.

## 2. Experiments

Figure 1 shows the cross-sectional view of Al interconnection and relevant quantities. Here, an aspect ratio (AR) is defined by the ratio of Al height $H$ to space $S$. Three kinds of aspect ratio structures were examined.

Figure 2 shows the process flow for the sample preparation and its condition. Al interconnections with line/space (L/S) of 0.4/0.8, 0.4/1.2 and 0.4/1.6μm were formed on underlying $SiO_2$ layer. After sintering, two kinds of passivation films were examined as the 1st passivation. One was the PSG (4%mol) and the other was the undoped silicate glass (USG) as the reference.




| L/S (μm) | 0.4 / 0.8 | 0.4 / 1.2 | 0.4 / 1.6 |
|---|---|---|---|
| aspect ratio | 1.0 | 0.67 | 0.5 |

*H* : Al height = 0.8μm

Fig.1 Cross-sectional view of Al interconnection. Aspect ratio (AR) is defined by H/S.

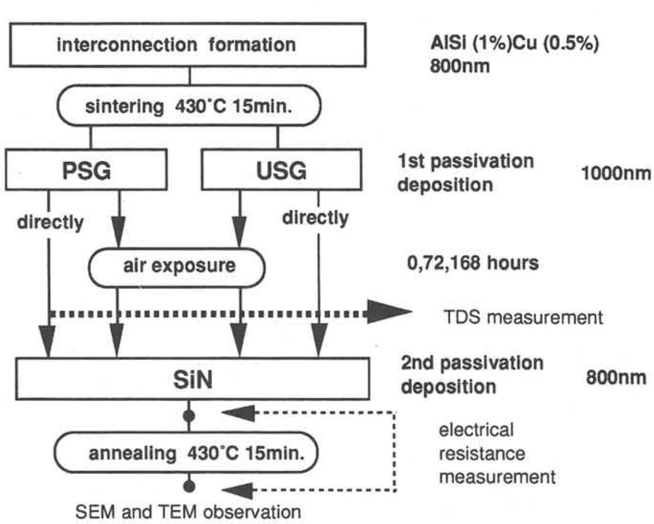



Fig. 2 Sample preparation and experimental conditions.

Then the specimens were exposed to air of 45% moisture under three kinds of exposure time 0, 72 and 168 hours. Finally, the SiN as the 2nd passivation was deposited. Annealing at the temperature of 430°C was made for 15 minutes.

Measurement methods are described as follows. $H_2O$ contents were evaluated by the TDS after the air exposure. Figure 3 shows a TDS example. Dashed area under 430°C of annealing temperature corresponds to effective $H_2O$ content. In order to estimate the relationship between $H_2O$ content in the 1st passivation and void formation of Al interconnection, we measured resistance of Al interconnections before and after annealing. The resistance after annealing increases with the increase of voids. SEM and TEM were used to observe the failure mode. The stress of SiN/PSG multi-layer was measured from wafer curvature during heat-up and down between the room temperature (RT) and 430°C.

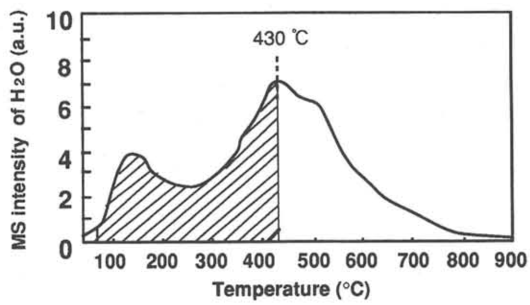



Fig.3 Mass spectrum (MS) intensity of $H_2O$ as a function of temperature by TDS. The effective $H_2O$ content is calculated by integrating MS intensity profile from RT to 430°C, i.e. dashed area.

## 3. Results and Discussions

Figure 4 shows that the $H_2O$ content in PSG drastically increases with the air exposure time, while that in USG is almost independent of the air exposure time. Figure 5 shows the relative resistance of Al interconnection as a function of $H_2O$ content. It is found that the relative resistance and its deviation increase with $H_2O$ content in the case of SiN/PSG and low AR. On the other hand, the relative resistance in the case of SiN/USG is almost constant.

Figure 6 shows SEM micrograph of Al interconnection in the case of SiN/PSG and AR= 0.5, where passivation film is removed. This specimen has a large increase in relative resistance after annealing.

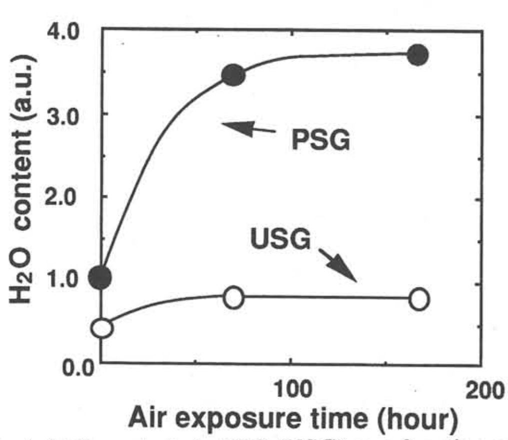



Fig.4 $H_2O$ contents in PSG (USG) as a function of exposure time after the film deposition.

Several round-shaped voids are generated and the conductor width becomes narrower at these point.

From these results, we emphasize that $H_2O$ in PSG plays a decisive role of void formation in the case of low AR.

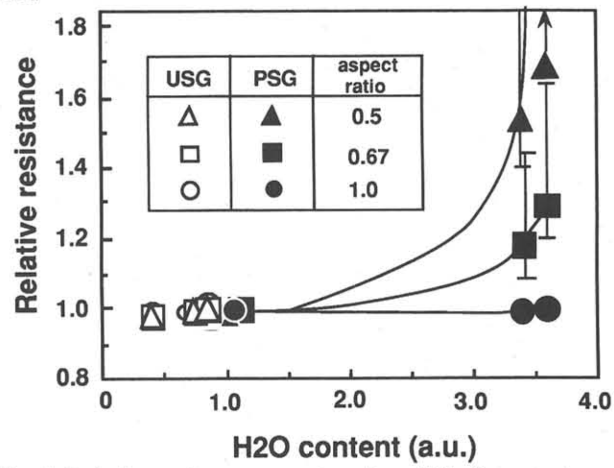



Fig.5 Relative resistance as a function of $H_2O$ content. The relative resistance is defined by the resistance ratio of after to before annealing.

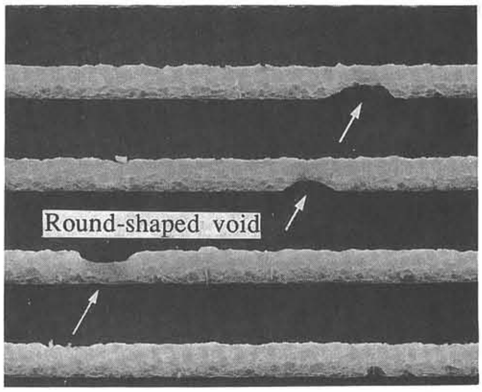



Fig 6 The oblique SEM view of Al interconnection after passivation removal. Round-shaped voids are observed. Passivation is SiN/PSG, AR is 0.5 and air exposure time is 168hours.

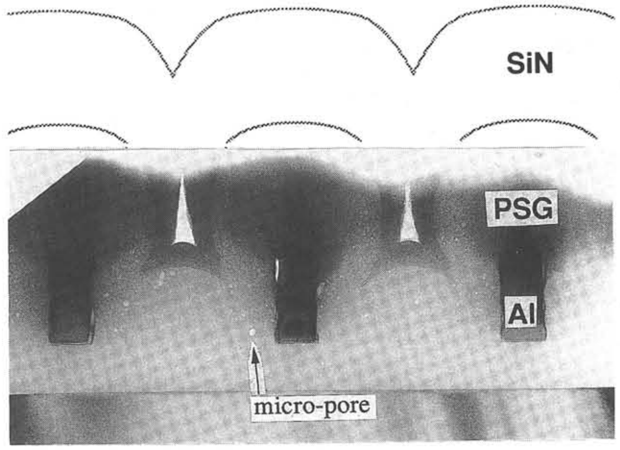



Fig.7 TEM micrograph of Al interconnections covered with SiN/PSG passivation. Maximum diameter of micro-pore is about 60nm. The sample is the same as that shown in Fig.6.

Figure 7 shows the TEM micrograph. The sample is same as that of Fig.6. Many micro pores are found in PSG layer for AR=0.5. On the other hand, the micro pores are not found in PSG layer for AR=1.0, even though the amount of $H_2O$ is the same each other.

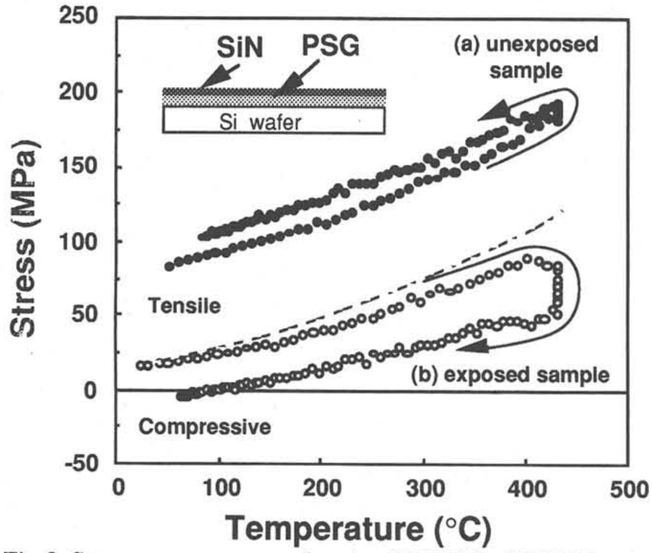



Fig.8 Stress measurement for the SiN/PSG (50/1000nm) passivation as a function of wafer temperature.
(a) 168hr air exposure case before SiN deposition.
(b) unexposure case before SiN deposition.
Dashed line shows the increase of sample (a) for comparing with sample (b).

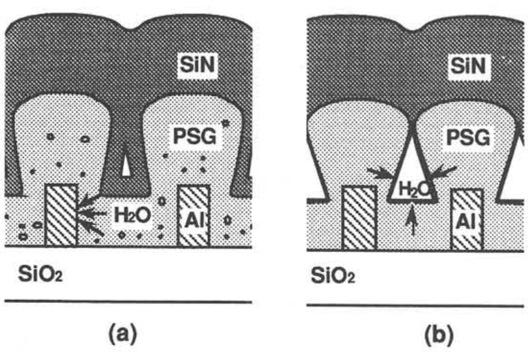



Fig.9 Cross-sectional models of Al interconnection covered with SiN/PSG passivation containing $H_2O$ in PSG.
(a): low AR (0.5), (b) : high AR (1.0).

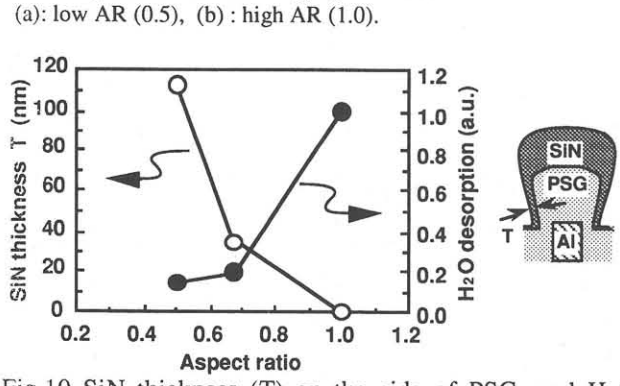



Fig.10 SiN thickness (T) on the side of PSG, and $H_2O$ desorption from PSG covered with SiN as a function of aspect ratio (AR).

In order to find the cause of micro pore generation mechanism, the stress of SiN (50nm) / PSG (1000nm) multi-layer on the Si wafer was measured as a function of wafer temperature as shown in Fig.8. The increase in tensile stress of air exposed sample (b) is smaller than that of unexposed one (a). The tensile stress for the sample (b) decreases when keeping the temperature at 430°C. In other words, compressive stress increases. This is because confined $H_2O$ may become high pressure steam and form the micro pores in PSG, since SiN(50nm) prevents $H_2O$ from desorption.

Figure 9 shows the model of $H_2O$ behavior in SiN/PSG passivation containing $H_2O$ in PSG. In the case of low AR in Fig.9 (a), $H_2O$ is confined in PSG by thick SiN passivation. The micro pores are formed in spherical shape because of the existence of high pressure $H_2O$ in PSG. The high pressure $H_2O$ steam attacks the surface of Al interconnection, which enhances round shaped void formation. In the case of high AR of Fig (b), relative resistance does not increase even for high $H_2O$ content and high AR as shown in Fig.5. Micro pores are not found in the same sample. The relationship between micro-scopic passivation structure and $H_2O$ desorption through the SiN passivation should be clarified.

Figure 10 shows both the thickness (T) of SiN coverage at the side of PSG and the $H_2O$ desorption by TDS from SiN/PSG as a function of the AR. In the case of high AR, the thickness (T) of SiN is so thin that $H_2O$ in PSG desorbs outside as shown in Fig.9 (b).

## 4. Conclusions

We have clarified the relation between $H_2O$ content in PSG and void formation of Al interconnection covered with SiN/PSG passivation at high temperature mode. High pressure $H_2O$ in PSG is confined by SiN as $H_2O$ proof material and attacks Al interconnects. As a result, the round-shaped voids are formed, accompanied by micro pores in PSG.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